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ABSTRACT

Presented is background information related to the third round of science assessment activities (1976-77) conducted by the National Assessment of Educational Progress (NAEP). Chapter one contains a description of the overall assessment plan, the general framework of objectives, criteria for selecting objectives, and procedures used for developing specific learner outcomes. Chapter two is focused on the cognitive domain while chapter three relates to attitudes, values, and experiences. Three appendices are included: (1) 1976-77 sample objectives, (2) a list of science consultants, and (3) objectives from cycles I and II. A short bibliography is included. (SA)

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SCIENCE OBJECTIVES

THIRD ASSESSMENT

SE 029 355

Science Objectives

for

The Third Assessment

by the
National Assessment of Educational Progress

Education Commission of the States
Suite 700, 1860 Lincoln Street
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CHAPTER 1

THE OBJECTIVES DEVELOPMENT PROCESS FOR THE 1976–77 SCIENCE ASSESSMENT

The changes in science education over the last 20 years have been dramatic, yet the general goals of science education have not changed radically. Science educators still support the statement made during the development of the 1965 National Assessment of Educational Progress (NAEP) science objectives: "The major purpose of science education is to develop scientifically literate individuals" (Merwin and Tyler, 1965, p. 30). While few argue that assertion, translating it into a structure that satisfactorily measures the attainments in science of American youth has been a long and difficult process.

Over the years, National Assessment has responded to the need for increasingly precise definitions and measurements of scientific literacy. The 1972–73 science objectives (see Appendix C) were a step in this clarification process, and this, the most recent compendium of objectives, is yet a further refinement of the basic task.

As it has in the past, National Assessment invited educators and consultants holding a wide range of philosophies about science to collaborate in defining consensus goals (see Appendix B). They were asked to create not only global objectives but also lists of specific attitudes and areas of achievement they felt were critical to scientific literacy. In addition, the educators were asked to consider the implications of their objectives for the development of new science assessment items and for the eventual reporting of survey results. Ideally, the goals they developed would represent a variety of viewpoints about science; take into account a diverse national student population; guarantee that the assessment would sample a representative range of science topics at various cognitive levels; and give specific guidance to item writers. The remainder of this chapter describes the process by which the educators and consultants accomplished their tasks.

The Overall Plan

As a first step in the developmental process, a Science Advisory Group was selected to formulate an overall plan and to develop an objectives framework (see Appendix B). The Science Advisory Group members were selected to represent a variety of perspectives, fields of experience and expertise. All are involved in science education at some level; over half have experience in curriculum development; several have advanced degrees in science; three have extensive professional involvement in education evaluation; and most have classroom experience. The group included representatives of the National Science Teachers Association, the National Association of Research in Science Teaching, the National Science Foundation, the American Association for the Advancement of Science and the National Association of Biology Teachers.

The Science Advisory Group recommended the development of: (1) a general framework or matrix in which objectives could be placed, (2) criteria by which objectives could be selected for inclusion in the framework and (3) a process by which the domain of science could be systematically sampled for important, testable, specific learner outcomes, rather than a complete list of specific outcomes for science.

The General Framework for Objectives

The Cognitive Domain of Science

The advisory group developed a two-dimensional matrix to serve as the general framework for development of objectives and exercises. The first dimension divided the cognitive domain of science into three major areas: *science content, processes of science,* and *science and society.* These three areas were then divided into nine more specific subareas, as follows:

Area I Science Content	Area II Science Processes	Area III Science and Society
Biology	Processes of inquiry	Persistent societal problems
Physical science	Scientific decision making	Science and self
Earth science		Applied science
Integrated topics		

These three areas and nine subareas are discussed in more detail in Chapter 2.

The Taxonomy of Education Objectives

A condensed and simplified version of the *Taxonomy of Educational Objectives, Cognitive Domain* (Bloom, ed., 1972) was adopted as the second dimension of the cognitive objectives matrix (Exhibit 1). The simplified taxonomy uses Bloom's first three levels – *knowledge, comprehension* and *application* – and a fourth level consisting of Bloom's levels of *analysis, synthesis* and *evaluation*. Percentage weightings, representing the advisory group's judgment about the relative importance of student outcomes at each of these levels and the proportion of assessment time that would be allocated to each level in an "ideal" assessment, were given each of the cognitive levels (Exhibit 1).

EXHIBIT 1. Cognitive Objectives Matrix

		Knowledge	Comprehension	Application	Synthesis	Percent Weighting
CONTENT	Biology					15
	Physical science					15
	Earth science					10
	Integrated topics					10
PROCESSES	Process/methods					18
	Decision making					12
SCIENCE AND SOCIETY	Societal problems					7
	Science and self					7
	Applied science					6
Percent Weighting		20%	20%	40%	20%	100%
						TOTAL

The Affective Domain

Although the matrix does not lend itself to affective measurement, the advisory group felt that the measurement of both attitudes toward science and experiences in science is important because these attitudes and experiences influ-

ence students' decisions and actions. There are no affective objectives per se, since science curricula seem to promote only vague, positive, affective objectives.

The task of identifying topics for affective measurement began with the advisory group. The topics were further defined during subsequent conferences, resulting in eight sets of affective exercises. These include attitudes toward science classes; personal involvement in science research and education; confidence in the scientific endeavor; and one set of experience questions measuring science-related experiences students have had and would like to have. These questions were designed so that most do not elicit "right" or "wrong" answers, thereby enabling schools, parents and students to judge for themselves the importance of various attitudes. Consequently, the affective assessment is more descriptive than evaluative. This affective area is described more fully in Chapter 3.

The Criteria for Selecting Objectives

The criteria against which sample objectives were evaluated were developed during the Science Advisory Group objectives conferences. The criteria list and examples of objectives meeting these criteria follow:

Criteria

The objective should:

1. Entail a basic concept that contributes substantially to the understanding of the nature of the subject area.

   Example: Comprehend the concept that the cell is the basic building block of living organisms.

2. Entail a key concept or idea necessary to understand other bodies of knowledge.

   Example: Understand the concept of half-life, with respect to phenomena such as pollutants, radioactivity, biodegradables and others.

3. Have a broad application beyond the curricular area.

   Example: Know that water is a factor in food and energy production and thus is of individual and worldwide importance.

4. Be personally relevant and applicable – contribute to the individual's survival, well-being and quality of life.

   Example: Know that each flammable substance has a set kindling temperature and that a flame is not necessary to start a fire. These facts should be considered in the design of buildings, consumer products, and so on.

5. Be useful in potential career preparation.

   Example: Be able to distinguish among a wide range of career possibilities that have a base in science and technology.

6. Contribute to effective social decision making, especially in regard to issues surrounding persistent societal problems and technological developments.

   Example: Comprehend that survival of the human race requires that we view the earth as a closed system (except for radiation).

7. Contribute to an understanding of self.

   Example: Know that offspring tend to resemble their parents.

8. Contribute to an understanding of the nature, potential and limitations of science.

   Example: Comprehend and be able to apply the scientific assumption that the world is intelligible, causal and not capricious in nature.

Development of Specific Learner Outcomes

Following the meetings of the Science Advisory Group, objectives conferences for each of the cognitive areas and the affective area were held. The process of filling out the framework with specific facts, concepts, principles, conceptual schemes and inquiry skills that were to be assessed was completed at these conferences. Because it was not practical to list all important objectives in science, a sizable, systematic sample of the important objectives in science education was generated – hence the term "sample objectives." Appendix A contains the full set of these sample objectives.

At each conference, from three to five educators with special expertise in a particular field of science education (e.g., biology) followed these steps to develop a set of sample objectives for one or two subareas of the science domains.

1. A comprehensive *outline of the content* of a particular subarea of science (e.g., biology) was drawn up. The outline was to serve as an organizer so that all important topics (e.g., topic: energy transformation; subtopic: photosynthesis) would be included.

2. From their experience and from curricular materials available at the conference, the participants generated *sample objectives* (e.g., the student should know that carbon dioxide, water and sunlight are the raw materials of photosynthesis).

3. After a set of sample objectives had been developed for a portion of the outline, the group *evaluated* the importance of each sample. Objectives were revised, rewritten or rejected at this point.

4. The relative importance of measuring each sample objective was *rated* separately for ages 9, 13 and 17.

5. Following the completion of Step 4 for all parts of the outline, the conference participants *weighted* — gave a rough percentage rating to — each main outline topic (e.g., heredity = 10% of biology). These weights were later translated into numbers of exercises required for each topic.

CHAPTER 2

THE COGNITIVE DOMAIN

This chapter describes the cognitive domain areas and the taxonomic level definitions used in the science assessment. Sample objectives for each area are in Appendix A.

Major Areas in the Cognitive Domain

The cognitive domain of science is divided into three major areas: (1) content, (2) process and (3) science and society. These three areas may be loosely redefined as: (1) the body of knowledge in science, (2) the process by which that body of knowledge emerges and (3) the implications for mankind of that body of knowledge.

Content

The content area of the matrix represents those facts, concepts, principles, conceptual schemes, inquiry skills and other aspects of science that are necessary for an understanding of the natural world. Included as content topics are the traditional disciplines of biological science, physical science, earth science and integrated topics.

Assessment in integrated topics includes the following subtopics: models, equilibrium, change, evolution, growth, time/space, systems, cycles and probability. Because these subtopics have elements common to the study of biology, physical science and earth science, the integrated topics objectives were developed to measure understanding of phenomena common to all content areas. For example, an objective concerning cycles could be measured by developing questions about biological rhythms, weather (the seasons) or electrical signals. In some cases, abstract systems with no discipline-related context were presented to students. Since most integrated topics are abstract, objectives were not developed for 9-year-olds.

The four content subareas are divided into the following topics:

Biological Science	Physical Science	Earth Science	Integrated Topics
Systematics	Matter	Meteorology	Models
Cell theory	Combinations	Geology	Equilibrium
Energy transformations	Waves	Oceanography	Change
Heredity	Mechanics	Astronomy	Evolution
Evolution	Electricity and magnetism		Growth
Ecology			Time/space
Behavior			Cycles
Growth and development			Probability
Germ theory and disease			Systems

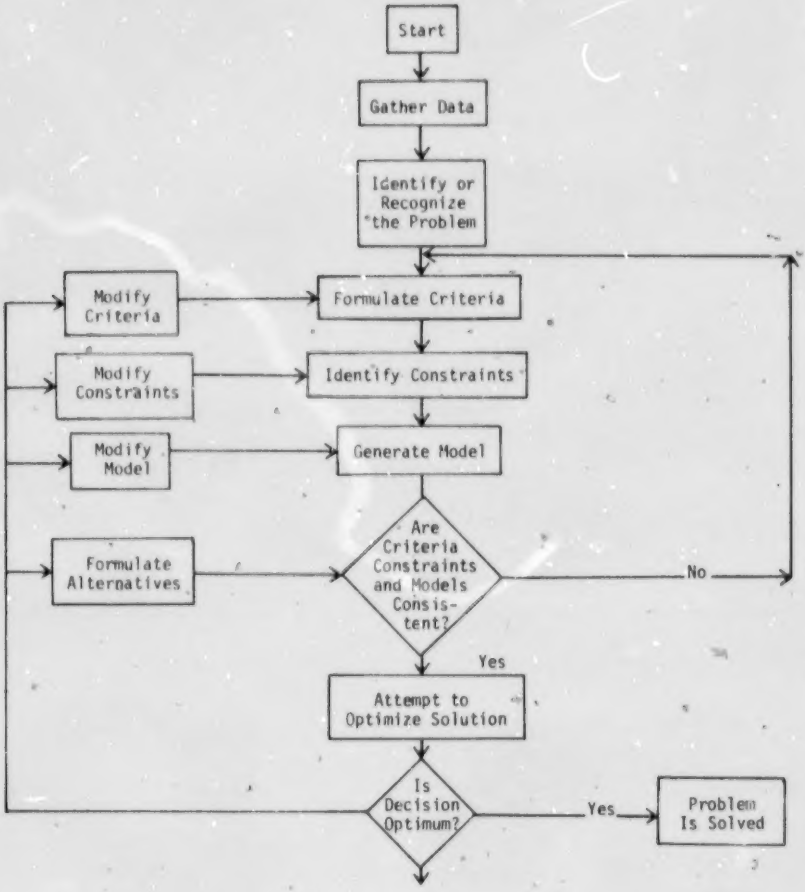
Processes of Science

Science curricula during the last two decades have placed increased emphasis on methods of thinking and acting that are applicable beyond the narrow limits of the science classroom. Measurement of students' knowledge of processes and ability to apply them reflects this new emphasis. The scientific process objectives are organized into two broad topics: (1) inquiry processes and (2) scientific decision making. They consist of generalizable methods, activities, inquiry skills, conceptual schemes and the empirical emphasis associated with the scientific endeavor.

The decision-making component of the objectives represented a new emphasis in the 1976–77 assessment. As science and technology continue to have greater implications for society and the individual, and as citizens increasingly make decisions regarding science and technology, the ability to make intelligent decisions is becoming an ever more important goal of science education.

Exhibit 2 illustrates the model used to develop the National Assessment decision-making objectives in science. While the flow chart is only one of many possible models, it does reflect the components of most other models.

EXHIBIT 2. Decision-Making Flow Chart



Topics within the scientific processes and their subtopics comprise:

Processes of Inquiry

Models
Assumptions
Communications
Measurements
Classification
Observing
Experimenting
Interpretation of data

Scientific Decision Making

Problem definition
Criteria development
Identification of constraints
Model generation
Developing solutions

Science and Society

The science and society area is divided into three general subareas: persistent societal problems, science and self, and applied science/technology. These subareas reflect the general goal of science education – that students should understand the implications of science for their own lives and the lives of other people.

The persistent-problems objectives address students' knowledge of current problem areas – e.g., population, energy use, pollution, resource management – and of the relative merits of potential solutions. The science-and-self objectives assess individuals' everyday use of science and personally relevant topics regarding individual health and safety. In addition to the cognitive objectives that appear in this section, there are many objectives scattered throughout other sections that meet the criterion of personal relevance. The affective assessment also measures a number of attitudes concerning interactions between the individual and science/technology.

As people become more involved in decisions about scientific and technological developments that affect their lives, it is necessary for them to understand the implications of technology. They need accurate information regarding the potential hazards of technological developments, and they need to be able to use this information to evaluate the relative merits of various alternatives. Objectives in applied science/technology are directed toward understanding those implications and facilitating those decisions.

The topics and subtopics included in science and society are:

Persistent Societal Problems	Science and Self	Applied Science/Technology
Health and safety	Everyday use of science	Applications in biological science
Environment	Personal health and nutrition safety	Applications in physical science
Growth	Personal contributions to conservation	Applications in earth science
Resource management	Individual responsibility regarding science-related societal problems	Changes in science/technology

Taxonomy of Education Objectives

A condensed and simplified version of the *Taxonomy of Educational Objectives, Cognitive Domain* (Bloom, ed., 1972) was used to guide development of specific objectives within each category of the content, process and science-and-society areas. A simplified interpretation of the taxonomy used in the science development (knowledge; comprehension; application; and analysis, synthesis and evaluation) follows.

Knowledge

Knowledge involves the recall of specific facts and universal principles, of methods and processes, or of patterns, structures or settings. Stated behaviorally, an example of an objective defined by the matrix as *knowledge of earth science* would be: "A student should know that earthquakes are more likely to occur in areas containing geologic faults."

Comprehension

Comprehension refers to a type of basic understanding by which the individual knows what is being communicated and can make use of the material or idea being communicated without necessarily relating it to other material or seeing its full implications. An example of a specific objective defined by the matrix as *comprehension of physical science* would be: "A student should be able to state Archimedes' principle in his or her own words."

Application

Application involves the use of abstractions in particular and concrete situations. Abstractions may be in the form of general ideas, rules of procedures or generalized methods. Abstractions may also comprise technical principles, ideas and theories that must be remembered and applied. An objective defined by the matrix as *application in biological science* would be: "From his understanding of the principles of photosynthesis, a student should be able to predict the effect of a decrease in solar energy on plant life."

Analysis, Synthesis and Evaluation

Analysis is the breakdown of a communication into its constituent elements or parts so that the relative hierarchy of ideas is made clear and the relationships between the ideas expressed are made explicit. Synthesis is the putting together of elements and parts so as to form a whole. Evaluation involves judgments about the value of material and methods for given purposes. A sample objective defined by the matrix as *analysis of methods* would be: "A student should be able to distinguish facts from hypotheses."

CHAPTER 3

ATTITUDES, VALUES AND EXPERIENCES

Many science educators consider attitudes and values to be among the most important education priorities. However, it is often inappropriate to make objective statements about how people *should* feel or think. Therefore, the affective components of the assessment were designed to be primarily investigative and descriptive – to find out what attitudes and values are held, and ultimately, how they change over the years.

The affective assessment is comprised of eight logically organized sets of exercises, each of which measures closely related attitudes considered important by science educators. The eight sets comprise:

- *Attitudes toward science classes.* Attitudes assessed in these questions are all related to classroom experiences. Does the student perceive science class(es) to be enjoyable and useful? Does the student believe teachers enjoy science and make it interesting? How do students perceive individualized activities in science class(es)? Checklist items have been included to assess the extent of students' extracurricular science activities, giving us indicators of whether or not they value science as an intellectual activity.

- *Vocational and education intentions.* These questions address students' attitudes and intentions regarding further study of science and the possibility of entering a career in a science-related field. Attitudes about these areas might seriously affect future numbers of workers in science and engineering.

- *Personal involvement in science.* The intent of these questions is to ascertain whether students believe society-related science problems affect them personally or whether students believe they can change societal conditions. For example, some questions were designed to see if students believe that current problems in energy, food production and overpopulation touch their lives. Students are asked if they believe they can make a personal contribution to the solution of a problem such as the energy shortage. Other items deal with whether or not students are willing to help solve problems.

- *Tools – attributes.* These questions assess students' opinions about the utility of the skills, procedures and philosophies of scientific investigation in their daily life. This includes the belief that what is learned in science classes in school is applicable to activities outside of school.

- *Confidence in science.* These questions are concerned with students' belief that science is a beneficial activity. Do students believe science can help solve world problems? Has science improved the quality of life? Questions elicit students' opinions of the degree to which social institutions such as the government should control science and scientific activities.

- *Support of research.* Students are asked to express their attitudes toward the conduct and support of research in basic and applied scientific fields. Attitudes toward such research could influence the direction such research takes in coming years.

- *Controversial issues.* A major theme in these questions is students' opinions and attitudes about important but potentially hazardous or controversial research topics. Students are asked if they believe research should continue in certain areas that entail trade offs between potential benefits and perhaps obvious risks. Though no "right" answer exists, it is important to determine students' opinions and shifts in opinion in these critical areas. A scientifically literate population should be able to make choices concerning such research and know the potential risks and gains in new research.

- *Awareness.* These questions determine whether or not students are aware of the assumptions, values and processes of science. Attitudes such as these tend to have a strong cognitive component, because, at the most basic level, they assess whether students are aware that the process of science exists. Awareness questions assess whether students apprehend the tentativeness of scientific theories, the fact that there are multiple solutions to problems, the fact that incomplete theories are useful, the role of self-criticism in science and the empirical base upon which science rests.

Experiences in Science

A ninth set of questions was also developed to measure students' experiences in science-related activities. One of the basic objectives of science education is to provide concrete experiences in the natural world. Data from these questions reflect the extent to which science education is meeting that goal.

APPENDIX A

1976–77 SCIENCE SAMPLE OBJECTIVES

Following are sample objectives used to stimulate the creation of exercises in each area and subarea. Although some are obviously more relevant to certain age groups than to others, all were considered potential sources of exercises aimed at all three ages. The samples should be taken as suggestive of the areas one would wish to cover; they are not definitive.

The Cognitive Domain

Biology: Germ Theory and Disease

Students should know that . . .

A balanced diet of fats, carbohydrates, proteins, vitamins and minerals is necessary for health and well-being.

The body has three major ways to protect itself from bacterial infection: (1) protective covering; (2) white blood cells that engulf microorganisms that have entered the body; (3) cells that produce antibodies able to interact with the bacterial toxin and render it harmless.

Frequent smoking of cigarettes is harmful to your health.

The ability to identify a disease with the pathogen is a step-by-step process (Koch's postulates).

Biology: Systematics

Students should know that . . .

Plants and animals may be differentiated by their characteristics.

There are different levels of organismal organization (cell-organ system).

Organisms are grouped on the basis of similarities.

Four basic characteristics separate living from nonliving things: metabolism, growth, reproduction and sensitivity.

Trees can be dated by the ring pattern in the xylem.

Biology: Cell Theory

Students should know that . . .

Cells are of diverse types and are adapted for different functions. The structure of the cell dictates to a large extent its function; e.g., nerve cells (long axons) transmit electron impulses.

There are two kinds of cell division: (1) mitosis = growth; (2) meiosis = preparation of gametes to reduce chromosome number.

The cell is the basic unit of structure and function of living things.

It is important to identify the functions of major components of a typical cell: nucleus, cell wall, chloroplasts, cell membrane, ribosomes, mitochondria.

Biology: Energy Transformation

Students should know that . . .

Carbon dioxide, water and sunlight are the raw materials of photosynthesis.

Photosynthesis captures (absorbs) solar energy.

Plants require the food they synthesize for energy.

Solar energy is captured for use in living systems by the process of photosynthesis.

Photosynthesis stores energy and respiration releases it.

Body temperature of healthy individuals varies.

Photosynthesis in plants is not able to occur without energy from a light source.

Biology: Heredity

Students should know that . . .

The terms *dominant* and *recessive* are important in genetics.

Offspring tend to resemble their parents.

Sex in humans and other animals is determined by the *x* and *y* chromosomes.

Many diseases are genetic in origin (hemophilia, etc.), and some are sex-linked.

A mutation is a change in a gene.

One can use Mendel's law to calculate elementary genetic probabilities.

Biology: Systems

Students should know that . . .

There are basic functions of the main organs and tissues of the body: stomach, heart, brain, bones, muscles.

A major function of the respiratory system is to provide a means by which excess carbon dioxide produced by the body's cells can be eliminated.

A major function of the respiratory system is to bring oxygen into the body in close proximity to the bloodstream, where it diffuses into the bloodstream and is carried to all cells of the body. Oxygen is needed by cells for metabolism.

The most common end product of carbohydrate digestion is the simple sugar glucose.

The heart is the pump for the human circulatory system.

The brain is the major center for the nervous system.

There are special organs with specific functions that are used in reproduction.

Biology: Evolution

Students should know that . . .

Fossils are one source of evidence for evolution.

An environment selects organisms best adapted to exist in its conditions.

Many more individuals are born in each generation than will survive and reproduce (biotic potential and limiting factors).

Individuals with certain characteristics have a better chance to survive and reproduce than individuals with other characteristics; some individuals are better adapted.

There is variation among the individual organisms of any population; e.g., with respect to food habits, insect coloration, etc.

Evolution means the change of organisms through time.

Biology: Ecology

Students should know that . . .

Populations fluctuate in size as a result of interactions between or among populations and/or their environments.

All things extrinsic to an organism that may impinge upon it are called the organism's environment. The environment comprises both nonliving and living factors; e.g., water, sunlight, temperature, wind and other organisms.

Living things are ultimately dependent on the sun; life is ultimately dependent on the sun.

Environmental factors exist within ranges (e.g., annual rainfall may range from 0 inches to 50 inches). Too much or too little of a factor can be harmful to an organism. There exists an *optimum range* for most factors (ecological habitat; biogeography).

The food pyramid is a way of showing that in an ecosystem, the *number* and *size* of populations usually decrease as one moves to higher trophic levels.

Animals are adapted to their environment (structure and function are related).

A population is a group of related organisms that live together.

The environment can support only a limited population.

As DDT and other substances that do not break down easily pass through food chains, they become increasingly concentrated in organisms in the higher trophic levels (biological magnification).

If almost anything in the environment is increased, it can become detrimental and therefore a pollutant.

Biology: Behavior

Students should know that . . .

Territoriality allows organisms to restrict an area for their own use.

Organisms commonly develop social hierarchies (pecking orders) that reduce stress in the population.

Animals communicate in many ways.

Behavior may be classified as innate (e.g., knee jerking, bee navigation) or learned (e.g., typewriting, driving a car).

Organisms respond to stimuli in the environment.

Biology: Growth and Development

Students should know that . . .

Developing plant and animal embryos both need food.

Seeds will germinate in both light and dark.

Plants grow toward light.

Cells of multicellular organisms divide, differentiate and specialize for specific functions.

Food is stored in a seed.

There is a sequence of events in the growth and development of a typical higher insect; e.g., zygote becomes larva; metamorphosis to pupa; metamorphosis to male/female adult, which produces sperm/egg that combines to form zygote.

Seeds are necessary for reproduction of many plants.

Some animals care for their young and others do not.

Plants obtain things such as water and minerals from the soil in which the plant is growing.

The six body parts a plant can have are the seed, root, stem, leaf, flower and fruit. Each part serves a specific function.

Physical Science: Matter

Students should know that . . .

The density of something is mass per unit volume.

Air is something that takes up space.

The atom is so small that it is not visible without sophisticated visual aids (e.g., electron microscopes).

The three states of water are solid, liquid and gas.

Everything is composed of atoms.

An element is a pure substance that does not break up under physical or chemical treatment.

Radioactive decay rates (half-lives) can be used to date many different things.

Air is the source of water.

Matter remains quantitatively constant in any system, and in any sequence of transformation of energy, no energy is gained or lost.

Displacement of the volume of liquid can occur when an object is placed in the liquid.

Water takes the shape of its container.

All matter is made up of atoms.

Most scientists believe that we cannot know exactly what atomic particles are going to do.

An ion has a certain identity and this knowledge applies to ionic solutions.

Organic chemistry is the study of carbon compounds.

Boyle's law and Charles' law can be applied to practical situations.

Physical Science: Combinations

Students should know that . . .

The masses of the products and the reactants in a chemical reaction do not change, as determined by a balance.

Combined materials are either a mixture or a solution.

There are various ways to keep iron from rusting.

Chemical reactions can be used to produce electric currents and vice versa.

Various factors affect the rate of a chemical reaction; e.g., concentrations, surface area, temperature and catalysts.

There are different ways of separating a salt-water solution.

A solution is one kind of a mixture. For a mixture to be a solution, it must be homogeneous and inseparable by ordinary mechanical means.

A dissolved substance can be recovered by boiling the water away.

Compound v. mixture: In a *mixture* of two or more substances, the molecules of the different substances remain unchanged, whereas, in *compounds,* molecules combine to form new substances.

Balancing a chemical equation involves understanding that in a chemical reaction, the mass of each individual element present is conserved.

In balancing a chemical equation, understanding chemical notation is necessary.

Chemical reactions can either absorb or release energy (endothermic v. exothermic).

Physical Science: Mechanics

Students should know that . . .

Speed is a distance/time relationship.

Acceleration is the change in velocity per unit time.

Newton's third law can be used to predict what would happen to the motion of one object in a given situation.

There is a relationship between the force exerted upon an object and its mass and resulting acceleration.

There is a difference between heat and temperature if operational definitions of both are presented.

They can demonstrate that they have a "feel" for the Celsius scale of measuring temperature.

Understanding of relative motion can be determined through application in an ordinary situation.

A change in the temperature of a substance results in an expansion or contraction of the substance and a change in density.

Conservation of energy is maintained, even if there is an immediate appearance of something for nothing; e.g., forest fire, dynamite explosion.

A balance beam, fulcrum and simple objects can be arranged so that the beam balances.

A force of gravitation exists between all objects and that this force decreases with distance.

They can describe what one needs to know in order to determine the quantity of heat absorbed by an object.

There are identifiable differences between the various means of heat transfer.

Melting always requires the addition of heat. A change of state requires energy.

The extent to which an object floats or sinks in water depends upon the density of the object.

The thermal expansion of a solid, liquid or gas can be compared and calculated.

Friction depends upon the materials that are in contact. Some materials are resistant to motion over another material.

An object going downhill changes velocity.

Friction between two objects causes vibrations that set up waves through the materials and produce heat.

Simple machines allow work to be increased.

Convection is the transfer of heat by another moving substance (e.g., a house is warmed by the circulation of hot air through the heating system).

Gravity is the force that tends to pull objects on earth toward the center of the earth.

The attractive force of all objects is expressed as $F = G(m_1 m_2 / r^2)$; or, the attractive force is directly proportional to the product of the masses of the bodies and inversely proportional to the square of their distances apart.

There is an identifiable variety of forms of energy (not potential – kinetic differences).

Time is dependent on the speed of travel.

Physical Science: Waves

Students should know that . . .

Reflected light follows a path so that the angle of incidence equals the angle of reflection.

Light can be bent by lenses to produce images (virtual and real)

White light is made of colored light.

Sound is transmitted by a vibrating medium.

Exposure to loud sounds over long periods of time can have a detrimental effect on an individual. The effect could be physical or emotional.

A shadow is the silhouetted image cast upon a surface by the imposition of a body between the surface and a light source obscuring the area between the surface and the interposed body. The length of the shadow depends upon the position of the light source and interposing body.

The transmission of sound in an area can be varied by the size and shape of the area as well as the materials used in construction of the area.

Wave and particle theories of light are somewhat competitive and contradictory. All aspects of light cannot be explained by the wave theory alone. There is a need for the particle theory.

Color is determined by the frequency of the light wave.

Visible light is only a small part of the electromagnetic spectrum, which is continuous from radio waves through light to gamma rays.

Physical Science: Electricity and Magnetism

Students should know or be able to . . .

Construct a sample series circuit consisting of a switch, battery and light.

Use various materials to determine whether a magnetic field exists in a region.

Determine the voltage produced by a number of cells in a parallel or series arrangement.

That a magnet will attract objects through different mediums.

That electricity is produced in various ways.

That electromagnetism is the production of magnetism in metals through use of electric currents flowing through a conductor. The electromagnet can be made by winding the conducting wire around an iron core.

That, in a closed circuit, electricity flows from one of the cell electrodes along the wire back to the other cell.

From a list of materials, separate those that are good conductors of electricity from those that are poor conductors.

Some of the things electricity can do; e.g., run motors, make light, make magnets, produce heat.

Distinguish which one of several circuits will light a bulb.

That household current is dangerous; specifically, one cannot experiment with it as one can with batteries, etc.

That a magnet will attract certain objects.

That there are major differences between a motor, a transformer and a generator; e.g., electricity to motion, electricity to electricity, motion to electricity.

That an electrical current in a wire will produce a magnetic field. The reverse will also happen if the magnetic field is changing.

That a charged particle follows a curved path in a magnetic field.

That, in general, a transistor is a device in which a small electric current controls a larger current.

That most of the universe is made up of positive and negative charges, but in nearly equal numbers so it isn't noticed. Static electricity occurs when there is a slight imbalance.

Earth Science: Meteorology

Students should know or be able to . . .

Use a synoptic weather map, a satellite photo or tabled data; analyze the atmospheric conditions at a location and predict changes in these conditions.

Observe and/or describe weather conditions. (Temperature, wind speed and direction, and precipitation are part of weather.)

Understand the underlying principles of weather forecasting.

Classify air masses by characteristics of source area.

Predict precipitation from given air mass characteristics.

That, when water evaporates, it becomes a gas and part of the air.

That wind is moving air.

Analyze those factors that determine climate – average weather patterns, latitude, altitude, large bodies of water, mountain barriers, wind belt, cause and effects.

Explain the moisture cycle of the atmosphere and the energy transfers involved.

Earth Science: Geology

Students should know that . . .

Plate tectonics is concerned with the relative movement and interaction of the plates of the lithosphere (surface and crust of the earth).

Groundwater supplies are being depleted.

Equilibrium tendencies drive the dynamic forces of earth change processes:

1. Gravity – erosion, transportation, deposition.
2. Interior heat cell – dynamic forces to produce vulcanism, diastrophism, plate shift.
3. Hydrologic cycle – heat distribution causing erosional agent of rain, etc.

There are similarities and differences between erosive factors on the earth and on the moon.

They can use cross sections, geologic map models and the principles of superposition, uniformitarianism and fossil correlation to interpret the geologic history of an area.

They can apply understanding of weathering and erosion to what we see at the surface of the earth.

The concept of erosion – peneplaination – may be used to help predict the future of a land form.

Sand is made by erosion.

Earth Science: Oceanography

Students should know that . . .

Estuaries are high in nutrients and serve as an incubator and nursery for many forms of ocean life; e.g., shrimp, crab, shellfish, flounder, halibut.

Life in the ocean is abundant where nutrients and energy are plentiful; e.g., in estuaries, upwellings, mixing layer.

They can describe the processes now being used to get economic products

from the sea and predict what materials will be gathered economically from the sea in the future.

Energy is distributed by ocean currents and affects human distributions.

Earth Science: Astronomy

Students should know that . . .

The sun is a direct energy source. The use of this energy could be as a large-scale energy resource for man.

The size of the universe exceeds any type of measurement we have available today.

All planets revolve in the same direction around the sun and rotate on their axes in the same direction.

There are various factors that influence the amount of insolation reaching the earth's surface; e.g., angle of incident clouds, pollution, length of day, etc.

They can recognize the constancy of the mass of the earth and demonstrate the variability of gravity with distance from the earth's center (outward from surface only).

Our sun is a star.

Time is a construct of man's mind based on observed regularity of certain phenomena. It has predictive value within the context of those phenomena. One can apply the concept of earth motions as being a frame of reference for time.

The earth is not the center of the universe, but rather is a small planet revolving around a minor star in an immense universe.

The declination of the sun results in the four seasons of the year.

The terms revolve and rotate apply to our solar system in certain ways.

Multidisciplinary: Models

Students should be able to . . .

Identify irrelevant details of a model – i.e., distinguish which details are necessary for its purpose and which are not.

Multidisciplinary: Equilibrium

Students should be able to . . .

Describe the effect of a disturbance on a system in (a) stable equilibrium; (b) unstable equilibrium.

and know that . . .

Changes in nature may occur under conditions in which the factors influencing a change tend to restore a "balance" of forces.

Multidisciplinary: Change

Students should . . .

Know all systems within the universe are in a constant state of change. The rate varies with the phenomena and conditions; e.g., chemical reactions, populations, land forms, cosmic phenomena.

Understand the concept of half-life; e.g., with respect to biopollutants, radioactive dating, DDT in ocean water, all biodegradables, radioactive waste, atmospheric pollutants such as ozone.

Multidisciplinary: Evolution

Students should know that . . .

Evolution is a systematic and directional series of changes that have predictive value.

Multidisciplinary: Growth

Students should understand that . . .

The concept of exponential growth is related to such elements of our environment as population, food production, consumption of nonrenewable resources, incubation periods for disease.

Multidisciplinary: Time/Space

Students should . . .

Comprehend the concept of time so that all phenomena – life, systems, cycles, change, ideas, etc. – can be understood and evaluated within its perspective.

Understand the concept of half-life; e.g., with respect to biopollutants, radioactive dating, DDT in ocean water, all biodegradables, radioactive waste, atmospheric pollutants such as ozone.

Multidisciplinary: Systems

Students should know that . . .

Explanations may be generated through recognition that two or more conditions or factors may mutually influence the action of each other; e.g., field-particle relations, ecological factors, adaptation, behavior of organisms.

Multidisciplinary: Cycles

Students should be able to . . .

Identify apparent cycles in a given situation and make predictions from them.

Multidisciplinary: Probability

Students should know that . . .

When statistical regularity is present, predictions with a stated probability of occurrence can be made.

Inferences and interpretations should be viewed in probabilistic terms rather than as absolutes.

Process/Methods: Models

Students should know that . . .

Scientific theories and models are dynamic (i.e., subject to change).

One test of a model is in the accuracy of the prediction.

Process/Methods: Assumptions

Students should know that . . .

Data should not be fabricated; science relies on observation, not authority or dogma; the difference between objectivity and amorality.

The laws (processes) of science are universal geographically (i.e., the same in all countries).

Science assumes the natural world is intelligible, not capricious.

Process/Methods: Communications

Students should know or be able to . . .

Translate numbers into graphs.

Translate a verbally stated relationship into an equation.

Communication plays an important role in science as it provides for the verification of results.

Communication is important because it is essential for cumulation of scientific knowledge.

There exists a vast network of communication journals in the sciences.

Process/Methods: Measurement

Students should . . .

Comprehend metric units sufficiently to give rough estimates of length, mass, temperature, volume.

Determine temperature change by subtracting initial from final reading on a thermometer.

Know the usefulness of estimation and adequacy of approximation for some purposes.

Know that averaging repeated measurements results in increased precision.

Know there is error in all measurement.

Know that, if you make measurements, you can communicate more effectively. You can also use mathematics.

Be able to interpolate or estimate – e.g., an arrow on a scale, markings on a thermometer.

Given two coordinates, be able to locate a position on a map; also, be able to describe the position of something on a map.

Know that, to interpret a change of relative position as evidence of relative motion, one must have reference objects and relative position; to exactly locate objects (whether on a rectangular grid or polar coordinates) one must have a working knowledge of the concept of relativity.

Process/Methods: Classification

Students should know or be able to . . .

Apply a common classification key: e.g., identify a given set of leaves.

Things are classified in particular ways for particular purposes.

Classification schemes are arbitrary and subject to change.

Analyze a simple classification system.

Select criteria upon which to classify objects.

Process/Methods: Observation

Students should know or be able to . . .

Arrange a series of pictures to show evidence of change, either in picture or in perspective.

The presence of the observer often affects the phenomenon observed; e.g., principal observing student behavior.

The nature of an observation is affected by the observer (experience, expectation, wishes). Science attempts to reduce bias.

Understand and apply concepts (reflection and refraction) in a simple demonstration.

Unexpected observations have played an important role in the advance of science.

Process/Methods: Experimentation

Students should . . .

Be able to identify proper experimental design.

Know that experiments are carried out under special, controlled conditions for specific purposes.

Be able to identify situations in which variables were either held constant or not held constant.

Given a phenomenon or event, be able to identify the critical variable or identify things that might affect the result.

Understand and apply the concept of magnetism in a simple experiment.

Process/Methods: Interpretation of Data

Students should . . .

Be able to interpolate data.

Be able to interpret patterns and trends from data; e.g., tables and graphs.

Be able to identify valid and nonvalid interpretations of data and why some interpretations are not valid.

Recognize limits of generalizability of particular experimental results using an obvious example.

Be able to select, from a larger set, those data that are pertinent to a particular question.

Given a set of data with a pattern, be able to extend the pattern and make predictions on the basis of information given.

Be able to translate from graphs to tables to words and back (especially line graphs, histograms).

Be able to extrapolate from a set of data.

Be able to summarize data.

Be able to read and interpret graphs.

Be able to identify and describe cause and effect in relation to a set of data.

Be able to differentiate between inference and observation.

Be able to identify apparent conflicts in sets of data or in experimental results.

Know that good theories are a concise, systematic view of a subject.

Be able to identify interpretations that are either supported or not supported by a particular set of data.

Science and Societal Problems: Health and Safety

Students should know . . .

That the U.S. ranks below 10th from best in infant mortality rate.

That basic first aid procedures are important.

That safe practices for self-preservation if caught in a public building fire include: (1) locate escape routes; (2) use stairs (fire ladders are too short for high-rise buildings); (3) keep wet towel over face.

That in the U.S., accidents are the major cause of death among persons aged 17–34.

That venereal disease is at an epidemic level in the U.S.

That some of the fundamental contributing factors for drug abuse are societal, family and peer-group pressures; availability; experimentation; medical prescriptions; advertising; inability to cope with rapid change and lack of understanding of self.

That fires need oxygen, heat and fuel to continue; this knowledge can be used to design fireproof (or fire resistant) homes.

That universal (large-scale) innoculation against diseases is important.

What addiction is, regarding: drugs, alcohol; what alcoholism is.

That each flammable substance has a set kindling temperature; the fact that a flame is not necessary to start a fire should be considered in the design of buildings, consumer products, etc.

Science and Societal Problems: Environment

Students should know that . . .

Man should seek the facts concerning environmental impact of projects before automatically accepting or rejecting plans for mines, highways, etc.

Our world contains harvestable resources, some of which are renewable and some of which are not.

Potentially widespread effects may result from local environmental disturbances that are not necessarily pollutive in nature; e.g., from regional weather control, dams, channeling, underground nuclear testing.

The role that persons and families have in contributing directly and indirectly to pollution is significant.

Pollution reaches a critical stage when the rate of injection of pollutants is greater than the capacity of natural forces to remove them.

Proposed solutions to particular pollution problems should be questioned with respect to potential side effects, which the solutions themselves may cause; e.g., the Aswan dam; nuclear energy to solve the energy problem leads to thermal pollution; solid and liquid waste disposal can lead to groundwater pollution.

Pollution may be either reversible or irreversible, depending on its nature and degree and the amount of time available.

Our atmosphere has a limited rate at which it cleanses itself of pollutants.

Given a set of pictures, they can be sorted into two groups: (1) helps environment, (2) hurts environment.

Pollution in a stream depends on rate of flow of the stream as well as rate of dumping and type of waste.

The effect of noise on a listener can be analyzed in terms of loudness, duration and pitch.

Temporary and permanent climatic changes are possible long-range effects of air pollution; e.g., of increases in carbon dioxide and solid particulate concentrations, changes in radiation belts.

It can be demonstrated that "solving" urban air pollution by banning incinerators may increase air pollution because of the additional trucks needed to haul garbage out of the city limits.

Science and Societal Problems: Growth and Resource Management

Students should know that . . .

From a model of population growth, population can be predicted 5–10–20 years hence and the relative accuracy of the predictions should be indicated.

Industrially developed countries use more energy and material resources per capita than underdeveloped countries.

Growing and shifting populations increase competition for water and bring about a need to formulate priorities for water use and/or develop better technology.

More food can be produced per unit of land if it is not converted to meat.

The "green revolution" (development of high-yield grains) has made short-range improvements in food production, but may create long-range problems – e.g., monoculture increases the probability of disaster.

The development or use of alternative energy sources should be supported to slow or avoid the depletion of fossil fuels.

We need to develop ways to tap new and various sources of energy.

The most serious part of the food problem is inadequate protein production.

There is a food supply problem in the world.

Energy problems are all interrelated; i.e., natural gas, petroleum and coal are used to make electricity, etc.

No modern industrialized or developed country has sufficient mineral resources to maintain its own economy (one world concept).

We can obtain energy from the sun, wind, tides, earth's core, etc.

The magnitude of solar energy (or thermal energy) available is huge compared with our current rate of consumption of energy.

Social and technological changes alter the interrelationships, importance and uses of natural resources.

Population growth is a worldwide concern, not just a concern of certain areas of the world.

Science and Self

Students should know or be able to . . .

When faced with a health problem, decide when it can be self-treated and when a doctor should be called.

The nutritional value of some basic foods.

Read and accurately interpret the advertiser's guarantee in ads, such as treatments for colds, weight reduction, cosmetics, etc.

Recognize and use approved methods for the care and use of electrical and gas-operated home appliances.

Realize that just because something is available for sale, that does not mean that it is safe to use.

Recognize simple indicators of bodily distress, such as choking, heart attack, shock, suffocation, etc.

Ways to personally control the wasteful use of gasoline, fuel, water, food, soil, etc.

Sources of reliable information for researching science-related problems; e.g., library, dictionary, *Handbook of Chemistry and Physics,* how-to-do-it books, *Readers' Guide,* science yearbooks.

Have a realistic attitude toward potential achievement in science careers.

A balanced diet of fats, carbohydrates, proteins, vitamins and minerals is necessary for health and well-being.

Frequent smoking of cigarettes is harmful to a person's health.

A balanced diet and exercise are important for a healthy body.

That first aid techniques are important.

Science and Technology (Applied Science): Biological

Students should know that . . .

One way to increase the world food supply is to breed plants and animals that yield more food per unit.

It would not be right to try to change people through genetic manipulations.

There are some social, political and economic implications and results of medical and other advances that prolong life, decrease infant mortality and eliminate disease; e.g., population growth.

Scientists should not try to develop new strains of bacteria, such as one more effective in nitrogen fixing, because they might produce a variation harmful to people.

The "green revolution" is an example of genetic manipulation in plants.

Science and Technology (Applied Science): Physical

Students should know that . . .

Appropriate trade offs are possible among positive and negative effects of weather control.

Research in miniaturization and the increased reliability of electronics for space expioration made possible other devices such as the heart pacemaker, automated beds for intensive care, etc.

Many synthetic materials require valuable resources (i.e., coal, oil, wood, natural gas, energy) for production; some do not (i.e., TVA production of phosphates).

Computers extend human mental capacity (much as engines have extended physical power) and relieve the necessity for doing calculations; they also enable us to make models.

Geologic factors (such as earthquake zones, flood plains, avalanche areas, water supplies, etc.) should be investigated before building houses, cities, etc.

The most characteristic feature of this period in our history is the effectiveness of our communication systems.

The transistor has made communication among scattered peoples possible in certain ways.

Technology that might result in products, services or personal needs that effectively create less pollution should be encouraged.

We should be sure we know what the effects of things like weather manipulation will be before we practice them on a large scale.

Decision Making

Students should know or be able to . . .

Evaluate data regarding usefulness and reliability.

One of the most direct ways to test a hypothesis is to make a prediction based on the hypothesis and then test the prediction by means of a controlled experiment.

Recognize appropriate methods of attack for problem solving.

Effective decision making requires the setting of goals and the recognition of limits.

Given a list of criteria statements, choose the one that most accurately defines the problem.

Recognize alternative solutions that are within criteria and constraints.

Recognize an appropriate model for a problem; e.g., verbal, graphic, pictorial, etc.

From a list of statements, select the one that implies the need for a decision.

Differentiate between objective and subjective criteria.

Differentiate between criteria and constraints: "Can we do this reliably and consistently?"

Value data; seek information.

The Affective Domain

Attitudes Toward Science Classes

To what extent are science classes enjoyable?

What is the student's favorite subject?

How does the student feel about science class(es)?

How does science class(es) make the student(s) feel?

Does the student have science in school? Would student enjoy more?

To what extent does the student perceive individualization in science class(es)?

Are science classes and activities individualized for students?

To what extent do science teachers enjoy science and reflect that enjoyment to the students?

Do science teachers encourage individualization in the students?

Do science teachers enjoy teaching science?

Are science classes useful?

How useful do students consider science classes to be in the real world, in everyday life or in general?

Is information gained from scientific experiments useful?

What extracurricular science-related activities do the students pursue?

What activities do students participate in that are not required for science classes?

Vocational and Educational Intentions

To what extent do students consider science as an area of further study and career possibilities?

How do students rate a science-related vocation?

Personal Involvement

Do students recognize serious problems in the world today?

Can students effectively do anything to solve major problems?

Are students willing to help solve major problems?

How often do students participate in activities that aid in solving major problems?

Tools – Attributes

Are the concepts and principles learned in science classes useful or applicable in everyday scientific investigation and decision making? In problem solving?

Confidence in Science

Do students believe that science can help solve world problems?

Support of Research

Determine the attitude students have toward the conduct and support (i.e., financial) for:

Applied research.
Basic research.

Controversial Issues

What are students' opinions and attitudes about allowing research in areas with potential hazards and risks?

Awareness

Are students aware of the scientific process and the empirical nature of science?

Are students aware of the tentativeness of scientific theories?

Experience

Experience – done something.

Have students ever done science-related activities?

Would students like to do science-related activities?

Experience – seen something.

Have students ever seen different events or activities related to science?

Would students like to see different events or activities related to science?

Experience – used something.

Have students ever used various science-related objects?

Would students like to use various science-related objects?

Experience – visited a place.

Have students ever visited various places related to science?

Would students like to visit various places related to science?

Experience – done experiments.

Have students ever done experiments or activities with various science-related things?

Would students like to do experiments or activities with various science-related things?

APPENDIX B

SCIENCE CONSULTANTS

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APPENDIX C

CYCLE I AND II OBJECTIVES

The purpose of this chapter is to provide a condensed version of Cycle I (1969–70) and Cycle II (1972–73) objectives. In this appendix, the structure and general objective statements of the earlier objectives are preserved, but age-specific examples are omitted.

Cycle I Objectives

Four primary objectives of science education were stated in the first objectives set. Those primary objectives are interdependent and are different facets of the same entity; their development in students proceeds concurrently as an integrated pattern. They are cumulative for 9-, 13- and 17-year-olds; i.e., it is assumed that 17-year-olds should know and be able to do everything that 13- and 9-year-olds should know and be able to do. However, this cumulative effect does not carry over to adults, who might have forgotten many of the details of the scientific principles they were exposed to in school. Nonetheless, adults' understanding and appreciation of science as a process should be developing, especially as science relates to individual and societal problems.

Objective I. Know fundamental facts and principles of science

A. Charge, momentum, mass-energy and the conservation of these quantities

B. Characteristics of electricity and magnetism

C. Characteristics of electromagnetic radiation

D. Atomic and molecular nature of matter

E. Discontinuities of matter

F. Classical mechanics (statics, dynamics, mechanics of continuous media)

G. Heat and simple kinetic theory

H. Nature (and control) of chemical reactions

I. Relation of structure of matter to behavior

J. Common types of chemical behavior

   1. Acids/bases

   2. Oxidation/reduction

   3. Elastomers and polymers

K. Minerals and rocks

L. Erosion and weathering

M. Land forms

N. Fossils and geological history

O. Internal constitution of the earth

P. Diversity of living things

Q. Organization of living matter

R. Metabolism

S. Behavior of organisms

T. Reproduction

U. Evolution

V. Ecology

W. Elements of atmospheric science

X. Solar system – its arrangement and dynamics

Y. Stars and galaxies

Z. Ages and dimensions within the universe – sense of scale

AA. Health and nutrition

BB. Nature and properties of matter

CC. Laboratory observations and techniques in chemistry

Objective II. Possess the abilities and skills needed to engage in the processes of science

A. Ability to identify and define a scientific problem

B. Ability to suggest or recognize a scientific hypothesis

C. Ability to propose or select validating procedures (both logical and empirical)

D. Ability to obtain requisite data

E. Ability to interpret data; i.e., to comprehend the meaning of data, and recognize, formulate and evaluate conclusions and generalizations on the basis of information known or given

F. Ability to check the local consistency of hypotheses with relevant laws, facts, observations or experiments

G. Ability to reason quantitatively and symbolically

1. Ability to understand and perform numerical operations

2. Ability to understand and use symbolic relations

3. Ability to understand and use information presented in graphs, charts, tables, diagrams, maps and verbal materials

H. Ability to distinguish among fact, hypothesis and opinion the rele-

vant from the irrelevant, and the model from the observations the model was derived to describe

I. Ability to read scientific materials critically

J. Ability to employ scientific laws and principles in familiar or unfamiliar situations

Objective III. Understand the investigative nature of science

A. Scientific knowledge develops from observations and experiments and the interpretation of the observations and the experimental results; such observations and experiments are subject to critical examination and to repetition

B. Observations are generalized in laws

C. Laws are generalized in terms of theories

D. Some questions are amenable to scientific inquiry and others are not

E. Measurement is an important feature of science because the formulation as well as the establishment of laws are facilitated through the development of quantitative distinctions. Measurements are inherent and only approximate, and are progressively inclusive and precise

F. Science is not, and will probably never be, a finished enterprise

Objective IV. Have attitudes about and appreciation of scientists, science and the consequences of science that stem from adequate understanding

A. Recognize the distinction between science and its applications

B. Have accurate attitudes about scientists

C. Understand the relationship between science and misconceptions or superstitions

D. Be ready and willing to apply and utilize basic scientific principles and approaches, where appropriate, in everyday living

E. Be independently curious about and participate in scientific activities

Cycle II Objectives

The 1972 National Assessment science objectives were divided into three primary statements describing the behaviors expected to be observable in individuals as they move toward the attainment of scientific literacy:

I. Know the fundamental aspects of science

II. Understand and apply the fundamental aspects of science in a wide range of problem situations

III. Appreciate the knowledge and processes of science, the consequences and limitations of science, and the personal and social relevance of science and technology in our society

The 1972 science objectives were organized in a manner that shows the relationship between behavioral processes (know, understand and apply, and appreciate) and the fundamental aspects of science. The three primary objectives are actually interdependent, and growth or learning in young people, although it is considered hierarchical to some extent, proceeds concurrently across these three objectives. That is, "knowing" may represent a lower level of interaction with content matter than "applying" and "appreciating," but any one of these processes may in fact precede and give rise to the others. The overall framework for the organization of the 1972 science objectives is shown in the following grid.

ELEMENTS OF SCIENTIFIC LITERACY: A TWO-DIMENSIONAL GRID USED IN THE ORGANIZATION OF THE SCIENCE OBJECTIVES

Objectives	Fundamental Aspects of Science				
	Facts and Simple Concepts	Laws (Principles)	Conceptual Schemes	Inquiry Skills	The Scientific Enterprise
Know	(I A)	(I B)	(I C)	(I D)	(I E)
Understand and Apply	(II A)	(II B)	(II C)	(II D)	(II E)
Appreciate	(III A)			(III B)	(III C)

The terms appearing in this grid are defined as follows:

Know. To know is to recognize or recall phraseology, textual material or other content. Knowing does not include or imply understanding, applying or appreciating.

Understand and apply. To understand is to be able to explain in one's own words, to recognize when stated in phraseology different from that in the textbook, or to interpret, such as in drawing inferences from tables or graphs of data. To apply is to make actual use of previously acquired knowledge. One must have knowledge and understand that knowledge before one can apply it. For example, the information on a weather map must be understood before it can be used to describe weather conditions in various parts of the country or predict the movement of high- and low-pressure areas for several successive days.

Appreciate. To appreciate is to value objects, ideas and processes. Appreciation is expressed behaviorally in willingness to attend, to give up resources for, to take a stand in favor of, etc. One must know about something in order to appreciate it, although he/she need not necessarily understand.

Fact. This is a simple description, definition or observation that many people can make; for example, "the grass is green"; "the dog has four legs."

Simple concept. An individual's generalized idea or mental picture of a property or set of objects, events or natural phenomena; for example, the idea of "dogginess" as a generalized category that includes specific dogs such as poodles, beagles and collies. A concept includes at least two facts with an internalized relationship and at least one that is not in agreement.

Law (principle). A law states a relationship between two or more concepts; for example, the law "force equals mass times acceleration" tells someone with adequate understanding of mass and acceleration and knowledge of mathematical symbols how the two terms are related. Laws are authoritative, can be agreed upon by others and can be tested. *Law* is presently the preferred term; *principle* is included because it appears in textbooks and reference sources.

Conceptual scheme. This means a broad theme of science, a synthesis of a group of interrelated laws (principles); for example, the theme of complementarity of organism and environment includes relationships between laws of energy resources in the environment, energy pathways, food webs, populations, and communities and ecosystems.

Inquiry skills. Those skills needed to engage in the process of science – for example, observation, hypothesis testing, data collection and ordering of knowledge.

The scientific enterprise. This is the contextual situation in which all science exists. It encompasses everything involved in science: the nature of the scientific method; relationships between science, technology and society; limitations of science; roles of scientists; and the like.

A description of the individual cells of the 1972 science objectives matrix follows.

Objective I. Know the fundamental aspects of science

A. Know facts and simple concepts. Know factual information and simple concepts representative of various fields of science and technology

1. Know terminology of science
2. Know names and uses of simple equipment used in science work
3. Know material objects
4. Know forms of energy
5. Know living things
6. Know some of the basic concepts of science
7. Know that knowledge can be classified
8. Know common mathematical and scientific symbols

B. Know laws (principles). Recognize the relationships involved in laws (principles). Naming the laws (principles) or recognizing the names is not necessary. Representative but not definitive examples include the following:

1. Know some principles related to the conceptual scheme of conservation of mass-energy

2. Know some principles of classical mechanics

C. Know conceptual schemes. Know some of the fundamental themes that pervade particular fields of science and the broad field of science. Examples of conceptual schemes include those developed for major science curricula (such as the Biological Sciences Curriculum Study or the Earth Science Curriculum Project) or the following seven conceptual schemes of science proposed by the National Science Teachers Association:

1. All matter is composed of units called fundamental particles. Under certain conditions these particles can be transformed into energy and vice versa

2. Matter exists in the form of units that can be classified into hierarchies of organizational levels

3. The behavior of matter in the universe can be described on a statistical basis

4. Units of matter interact. The bases of all ordinary interactions are electromagnetic, gravitational and nuclear forces

5. All interacting units of matter tend toward equilibrium states in which the energy content (enthalpy) is a minimum and the energy distribution (entropy) is most random. In the process of attaining equilibrium, energy transformations or matter transformations or matter-energy transformations occur. Nevertheless, the sum of energy and matter in the universe remains constant

6. One of the forms of energy is the motion of units of matter. Such motion is responsible for heat and temperature and for the states of matter: solid, liquid and gaseous

7. All matter exists in time and space; and, since interactions occur among its units, matter is subject in some degree to changes with time. Such changes may occur at various rates and in various patterns

D. Know inquiry skills

1. Know common approaches to scientific inquiry

a. Identify common examples of scientific questions

b. Recognize statements that qualify as scientific hypotheses

c. Recognize important aspects of testing procedures (both logical and empirical) in laboratory investigations that are commonly taught

2. Know fundamental techniques associated with inquiry

3. Know mental elements associated with inquiry

E. Know the scientific enterprise. Have a cognitive grasp of the major aspects of the scientific enterprise, including its products, processes and practitioners, and of the totality of its meaning

1. Know that laws (principles) of science and technology apply to the solution of problems relating to human welfare

2. Recognize how scientific knowledge can develop. For example, recognize that scientific knowledge can develop both inductively and deductively; recognize that observations and experiments are subject to critical examination, replication and human error; recognize that science is both a means and an end

3. Know that pure science is a search for basic knowledge and that applied science (technology) is a search for uses of knowledge

4. Know some of the historical aspects of the sciences and technology

a. Identify important living and nonliving scientists with their contributions

b. Know that scientific and technological developments de-

pend on the prevailing cultural, economic, social and political conditions

c. Know that the events of history have contributed to the scientific enterprise

d. Recognize the historical sequence of some of the major scientific events; recognize the cumulative nature of history and of knowledge in science

5. Recognize that most questions are amenable to inquiry by scientific methods

6. Recognize that measurement is an important feature of science

7. Recognize that science is not, and probably never will be, a finished enterprise

8. Have accurate perceptions about scientists as people

a. Perceive what scientists are like as people: perceive that their lives and personalities are similar to and as varied as those of other people

b. Perceive the role of scientists as that of uncovering and developing knowledge; know that there are limitations on what scientists can do; have realistic perceptions of the abilities and power of scientists

c. Recognize the nature of the training and/or experience (sometimes extensive) needed by scientists and technologists

Objective II. Understand and apply the fundamental aspects of science in a wide range of problem situations

A. Understand and apply facts and simple concepts

1. Apply terminology of science

2. Apply knowledge of simple science equipment

3. Apply knowledge of properties of material objects

4. Apply knowledge of forms of energy

5. Apply knowledge of living things

6. Use knowledge of basic concepts of science

7. Use appropriate categories to organize knowledge

8. Use common mathematical and scientific symbols

B. Understand and apply laws (principles). Understand laws (principles) of science and apply them in order to solve problems in familiar situations and in situations different from those in which the laws (principles) were learned

1. Apply some principles related to the conceptual scheme of conservation of mass-energy

2. Apply some principles of classical mechanics

C. Understand and apply conceptual schemes. Understand and apply the fundamental themes of the particular fields of the broad field of science

D. Understand and apply inquiry skills

1. Apply common approaches to scientific inquiry to answer questions in science and in everyday life

a. Formulate scientific questions

b. Develop scientific hypotheses

c. Select or propose testing procedures (both logical and empirical)

d. Obtain pertinent data. For example, is able to assemble and use laboratory equipment in a logical sequence, select and use appropriate laboratory techniques, make careful observations and make suitable measurements

e. Express data in proper convention and interpret data

f. Formulate and evaluate conclusions and generalizations appropriate to data or information given or obtained from experiments

2. Use fundamental techniques associated with inquiry. Use techniques such as the following in collecting information or in working with information given:

   a. Observing

   b. Measuring

   c. Classifying

   d. Communicating

   e. Predicting

   f. Inferring

   g. Consulting appropriate sources of information

3. Use mental elements associated with inquiry

   a. Distinguish among fact, law, hypothesis, assumption and opinion, and describe their relationships in inquiry. Generate examples of each

   b. Distinguish between relevant and irrelevant information

   c. Distinguish between a model and observations the model was invented to describe. Generate examples

   d. Distinguish between observations and inferences. Make observations free of inference

   e. Distinguish between inductive and deductive reasoning. Reason inductively or deductively when appropriate to do so

4. Attend critically to scientific information presented by the mass media

E. Understand and apply the scientific enterprise. Have a valid understanding of the scientific enterprise and give evidence of that understanding in one's behavior. Make enlightened use of this understanding

1. Have enlightened understanding of the social and economic consequences of the scientific enterprise

2. Make appropriate generalizations about the development of scientific knowledge

3. Distinguish between pure science and applied science (technology)

4. Use historical information about the sciences to understand present-day science and technology

5. Understand that most questions are amenable to inquiry by scientific methods

6. Understand that measurement is an important feature of science

7. Understand that science is not, and probably never will be, a finished enterprise

8. Interact with scientists as with any other people, without the unrealistic expectations, fears or reverence that would follow from categorization and stereotyping

Objective III. Appreciate the knowledge and processes of science, the consequences and limitations of science, and the personal and social relevance of science and technology in our society

A. Appreciate facts and simple concepts, laws (principles) and conceptual schemes. Appreciate science as a dynamic body of knowledge

1. Be willing or likely to apply basic scientific concepts and laws (principles), where appropriate, in everyday living

2. Have an interest in current news of a scientific nature

3. Value the structural framework of science and the elegance of scientific explanation

B. Appreciate inquiry skills as fundamental tools for solving problems

1. Be independently curious about scientific inquiry

2. Participate willingly in scientific inquiry

3. Recognize the importance of having quantifiable data

C. Appreciate the scientific enterprise. Have one's value system affected by his/her understanding of the scientific enterprise. Appreciate the need for, and value of, the activities and products of science

1. Appreciate the nature of the scientific enterprise, especially seeing its emphasis on reason and its opposition to mystical explanation as profoundly shaping the history of Western civilization

a. Skepticism of mystical explanations (for example, horoscopes)

b. Preference for and confidence in scientific explanations

c. Faith in the possibility of solving problems

d. Desire for experimental testing

e. Delight in the richer, more exciting view of the world generated by science education

2. Appreciate the interrelationships within the various branches of science and between science and other disciplines (including the humanities)

3. Appreciate the interrelationships between pure and applied science

4. Appreciate scientists; acknowledge the role of scientists in working for solutions to present-day problems; acknowledge the respected place of various scientists esteemed throughout history. Believe scientists are valuable people

5. Show appreciation of and interest in scientific activities

BIBLIOGRAPHY

Bloom, Benjamin, ed. *Taxonomy of Educational Objectives: The Classification of Educational Goals, Handbook I, Cognitive Domain.* New York: David McKey Co., Inc., 1972.

Merwin, Jack and Ralph Tyler. Working Paper on Objectives. Ann Arbor, Mich.: Exploratory Committee on Assessing the Progress of Education, November 15, 1965.

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